MEMS FOR SPACE FLIGHT APPLICATONS

Russell A. Lawton

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, Ca
Tel. (818) 354-6167
FAX (818) 393-4559
Email: Russell.A.Lawton@jpl.nasa.gov
http:\\parts.jpl.nasa.gov

MEMS FOR SPACE FLIGHT APPLICATONS

Micro-Electrical Mechanical Systems (MEMS) are entering the stage of design and verification to demonstrate the utility of the technology for a wide range of applications including sensors and actuators for military, space, medical, industrial, consumer, automotive and instrumentation products.

Failure analysis and process characterization of MEMS is critically needed for the successful design, fabrication, model verification, performance analysis and reliability assurance of this new technology. Many devices have been examined using techniques developed for integrated circuit analysis, including optical inspection, scanning laser microscopy (SLM), scanning electron microscopy (SEM), focused ion beam (FIB) techniques, atomic force microscopy (AFM), infrared microscopy (IR), light emission microscopy (LE), and acoustic microscopy.

The next move requires investigating the material dynamics in environments, where gases, temperatures and forces can be controlled and adjusted in-situ to investigate the process dynamics, and effects of material property macro vs. micro scaling issues.

The use of standardized test structures run on multiple process lines will allow for the understanding of intrinsic failure mechanisms and the nature of the risks associated with different processes for specific MEMS applications.

This presentation provides examples of an approach for experimental characterization of MEMS devices, to provide Reliability data for Risk Assessment for Space Flight Applications for MEMS.

MEMS FOR SPACE FLIGHT APPLICATONS

- **PROGRAM GOALS (NASA HQ)**
- **WHAT'S MEMS/MNT**
- **WHY MEMS**
- **CURRENT MEMS IN SPACE ENDEAVORS**
- **PROBLEMS WITH MEMS IN SPACE**
- **MEMS RELIABILITY**
- **MODELING**
- **CHALLENGES**

PROGRAM GOALS

- **PROGRAM: MEMS RELIABILITY ASSURANCE**
- **PURPOSE: Evaluate the technology and prepare the infrastructure for insertion in space applications.**
- **PRIMARY DELIVERABLES: Reliability assurance practices.**
- **MEMS CHARACTERIZATION:**
- **PURPOSE: Support characterization of MEMS Actuators and Sensors and provide methods for reliability assurance**
- **PRIMARY DELIVERABLES: Characterization results of MEMS Actuators and Sensors/Environmental characterization reports**

PROGRAM GOALS
(CONT'D)

- **MEMS FAILURE MECHANISMS:**
- **PURPOSE: Collect information on common failure mechanisms of identified MEMS designs**
- **PRIMARY DELIVERABLES: Failure Mechanisms with supporting data/Recommendations for failure avoidance and process improvements**
- **MEMS QUALIFICATION GUIDELINE:**
- **PURPOSE: Develop a Qualification Guideline for Space applications of MEMS useful for manufacturers and users**

WHAT'S MEMS/MNT

- **MICROELECTRO MECHANICAL DEVICES CONSTRUCTED WITH "SEMICONDUCTOR LIKE" PROCESSES**

  - ☆ **ANALOG DEVICES ADXL-50, ADXL-202**
  - ☆ **HP INKJET**
  - ☆ **TI MIRROR ARRAY - PROJECTION SYSTEM (DLP)**
  - ☆ **AURA SYSTEMS - ACTUATED MIRROR ARRAY- LARGE, THIN MONITORS**
  - ☆ **BIOLOGICAL - ELECTRONIC NOSE CYRANO Sciences**

WHY MEMS ?

SILICON PROCESSING TECHNIQUES ALLOW LOWER PER UNIT COST

- ☆PRESSURE SENSORS
- ☆ACCELEROMETERS
- ☆BIOMEDICAL DIAGNOSTIC SENSORS

SPACE SYSTEMS ARE PUSHING FOR NANOSATELLITES USING MEMS TECHNOLOGY

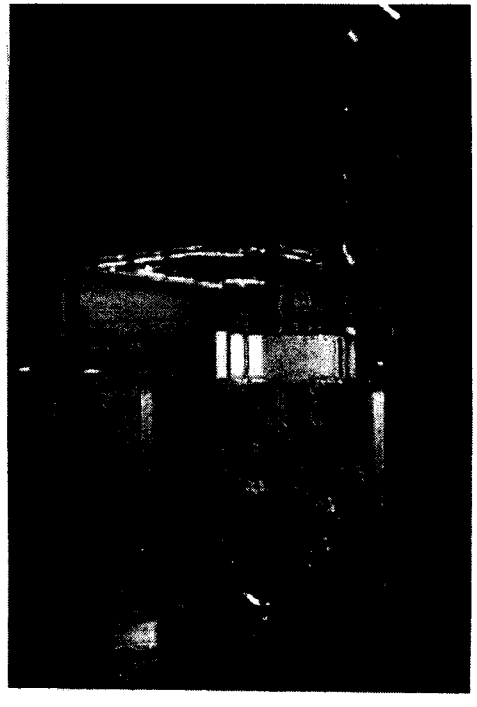
- ☆ LOW COST TO ORBIT DUE TO DECREASED WEIGHT
- ☆ LOW COST / LOW POWER
- ☆ LARGE CONSTELLATIONS DISPOSABLE SENSORS
- ☆ LAUNCH BASE / VEHICLE INSTRUMENTATION

CURRENT MEMS IN SPACE ENDEAVORS

- JPL SEISMOMETER STRV2 - MARS PENETRATOR
- AEROSPACE ACCEL TESTBED FOR STS-Launch
- JPL/UCLA MICROGYRO X-33
- JPL + AEROSPACE GYRO / INS DEVELOPMENT
- AIRFORCE ACADEMY - MIGHTY SAT

CURRENT MEMS IN SPACE ENDEAVORS

- AEROSPACE MEMS DISTRIBUTED SENSOR NETWORK
- LAUNCH VEHICLE CHARACTERIZATION
- LAUNCH BASE MONITORING
- ESA TEAMSAT



PROBLEMS WITH MEMS IN SPACE

- LONG TERM RELIABILITY - UNKNOWN
- PACKAGING OFTEN CHANGES DEVICE CHARACTERISTICS
- RADIATION EFFECTS - UNKNOWN

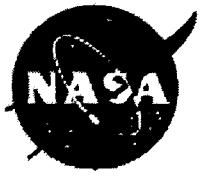
AREAS TO BE INVESTIGATED

- LIFE-SPAN
- ENVIRONMENTAL FACTORS
- PACKAGING TECHNOLOGY
- RADIATON EFFECTS

PROBLEMS WITH MEMS IN SPACE

Launch & Space environment

- Thermal, shock, vibrations
- Charged particle radiation from electrons & protons
- Erosion by atomic oxygen (lower orbits)
- Irradiation from solar ultraviolet
- Contamination from out gassing
- Vacuum
- Hypervelocity impacts



MEMS RELIABILITY

RELIABILITY ACTIVITY

- ☆ DESIGN and PROCESS CHARACTERIZATION
- ☆ MODEL VERIFICATION
- ☆ YIELD IMPROVEMENT
- ☆ FAILURE MECHANISMS
- ☆ RADIATION EFFECTS

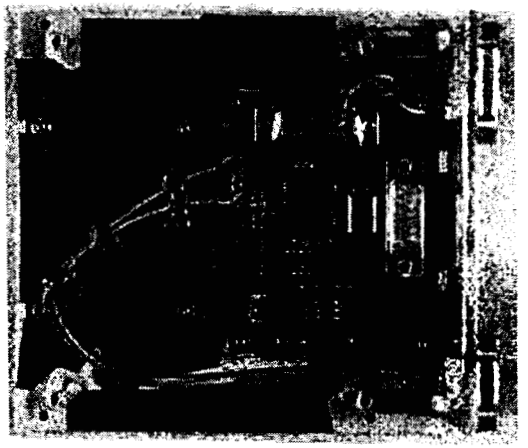
HOW WE WILL APPROACH THE PROBLEM

- ☆FUNDAMENTAL SCIENCE INVESTIGATIONS
- ☆MATERIAL PROPERTY SCALING ISSUES
- ☆ (MACRO VS. MICRO MECHANICAL PROPERTIES)
- ☆TEST INSTRUMENTATION DEVELOPMENT
- ☆NON-DESTRUCTIVE REAL -TIME TESTING
- ☆LAB IN THE CHAMBER (ESEM, RGA, IR, THERMAL, AFM)

SPECIFIC EXAMPLES
CONT'D

SENSORS

- MAGNETOMETER JPL/UCLA
- ELECTROMETERS JPL/BSAC
- MICRO GYRO JPL/UCLA
- ACCELEROMETER CIT
- ACCELEROMETER JPL/STANFORD

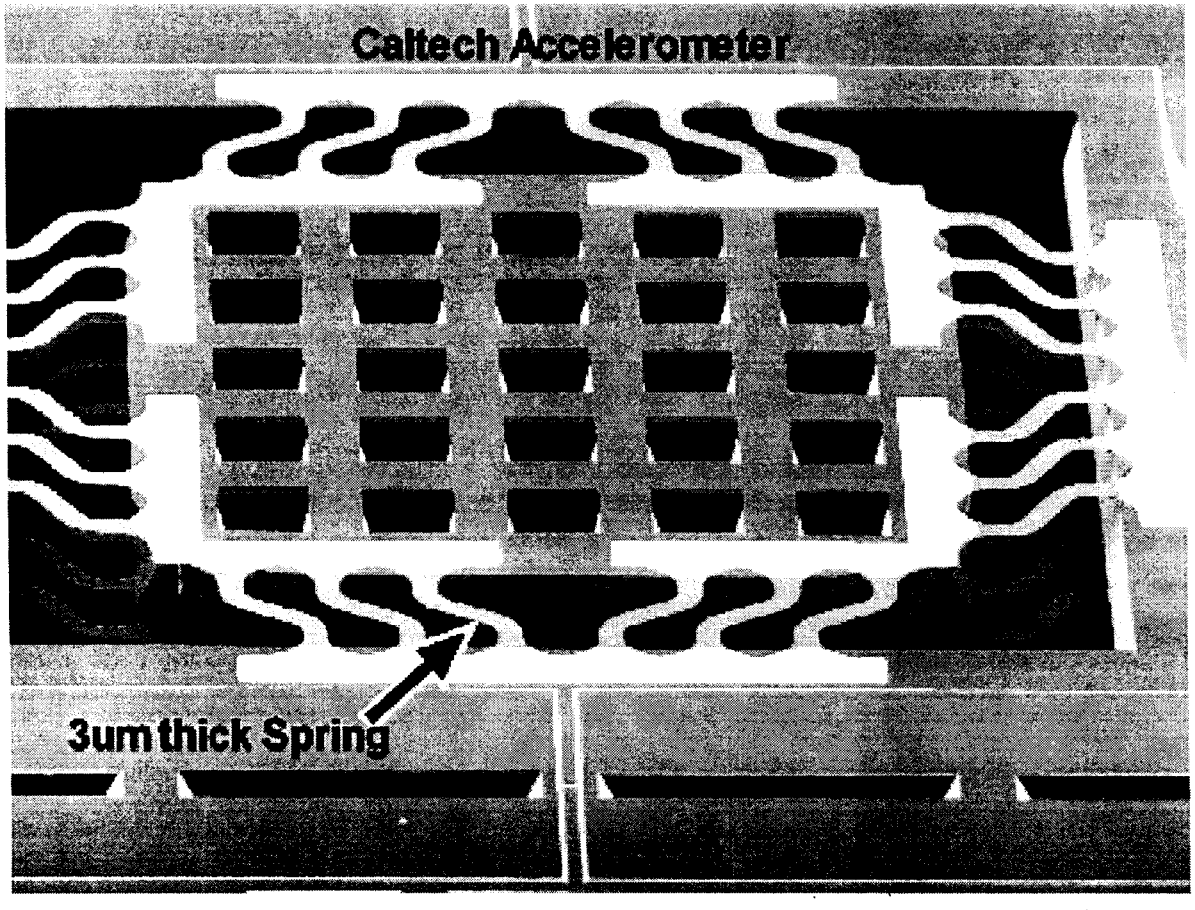


ACTUATORS

- RESONANT BEAM STRUCTURES ON MULTIPLE PROCESS LINES (MCNC,SANDIA,MOSIS,OFFSHORE, COMMERCIAL FOUNDRIES)
- MICRO MOTORS CIT/JPL

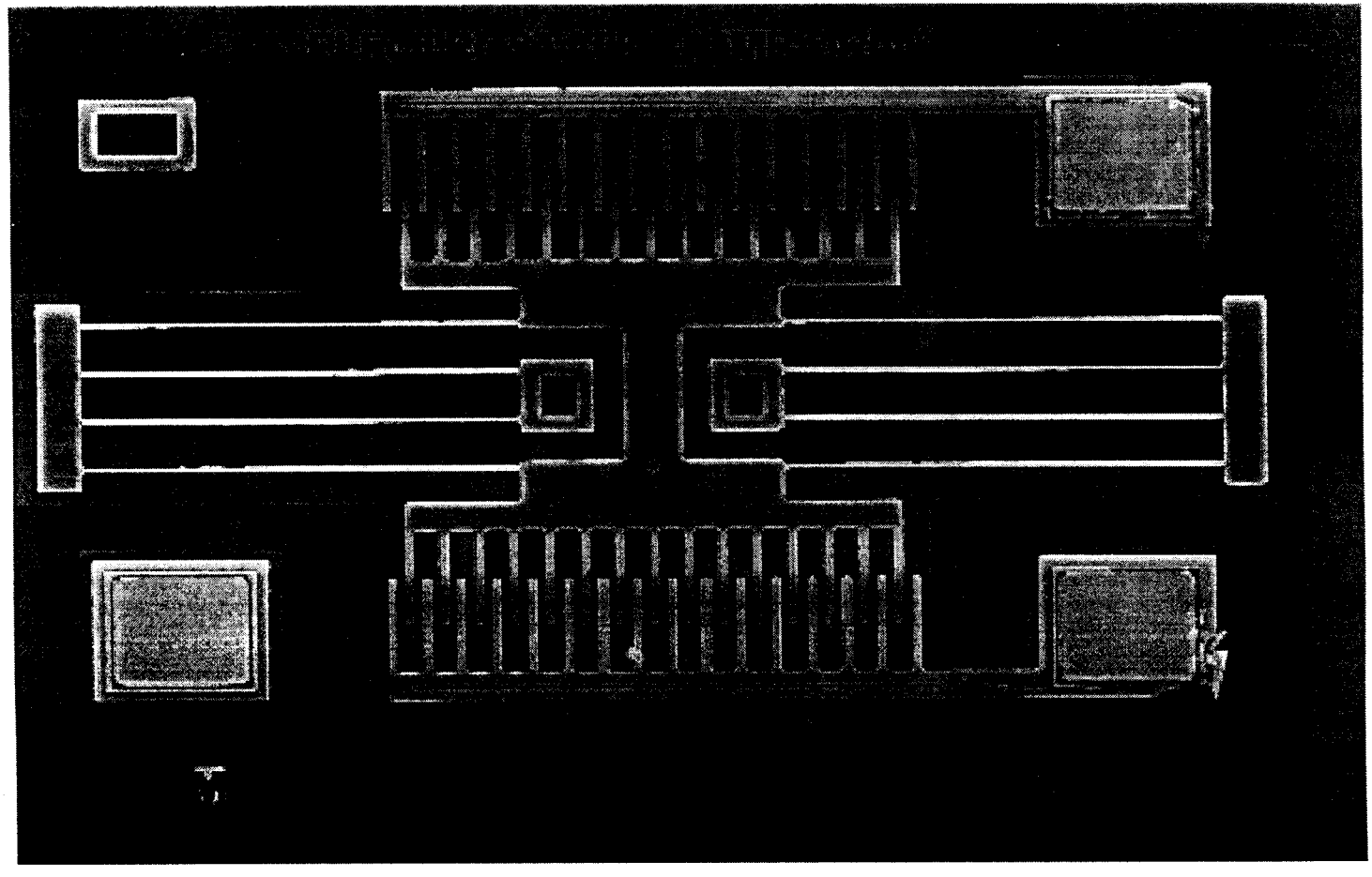
Caltech Accelerometer

Fabricated at MDL CIT



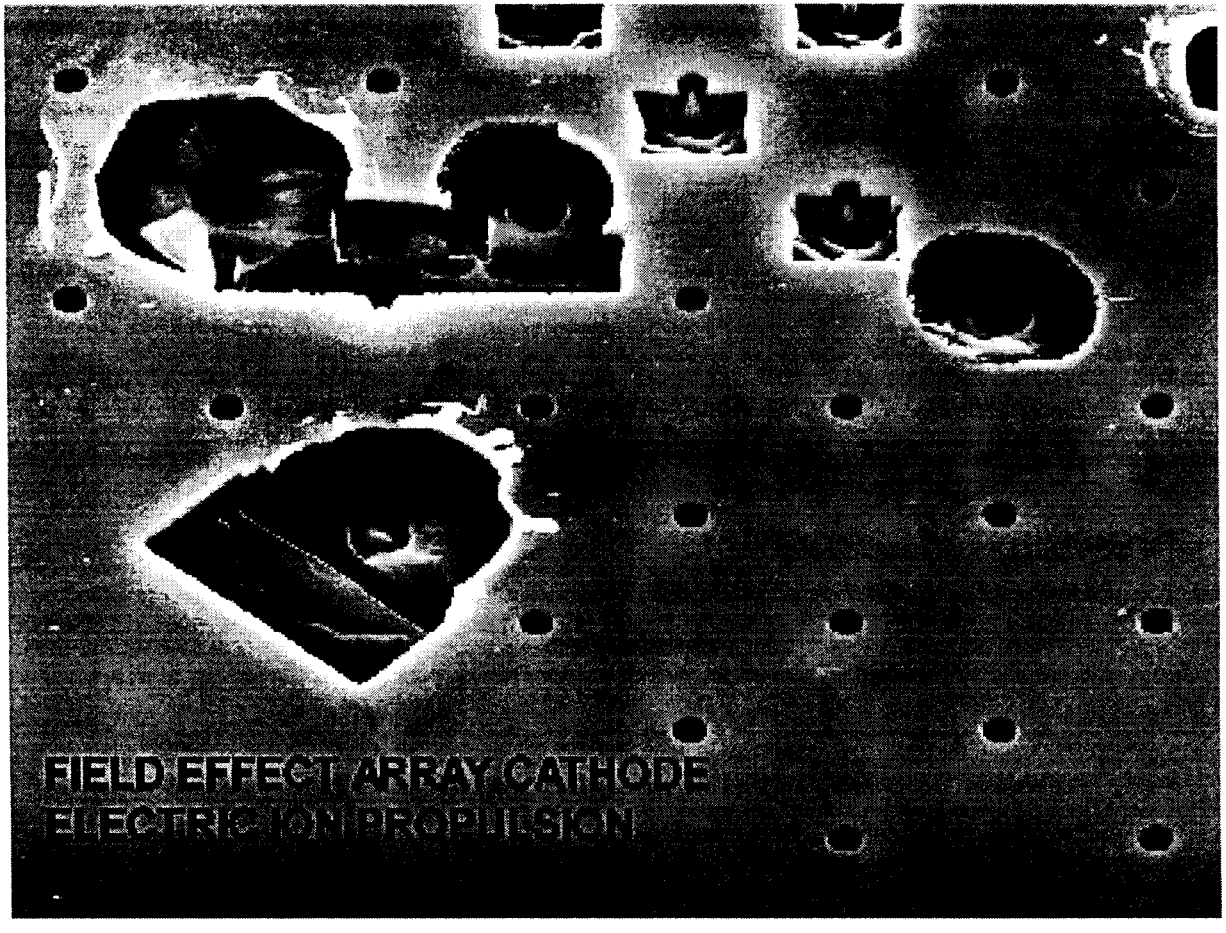
MCNC MUMPS

RESONANT BEAM STRUCTURE



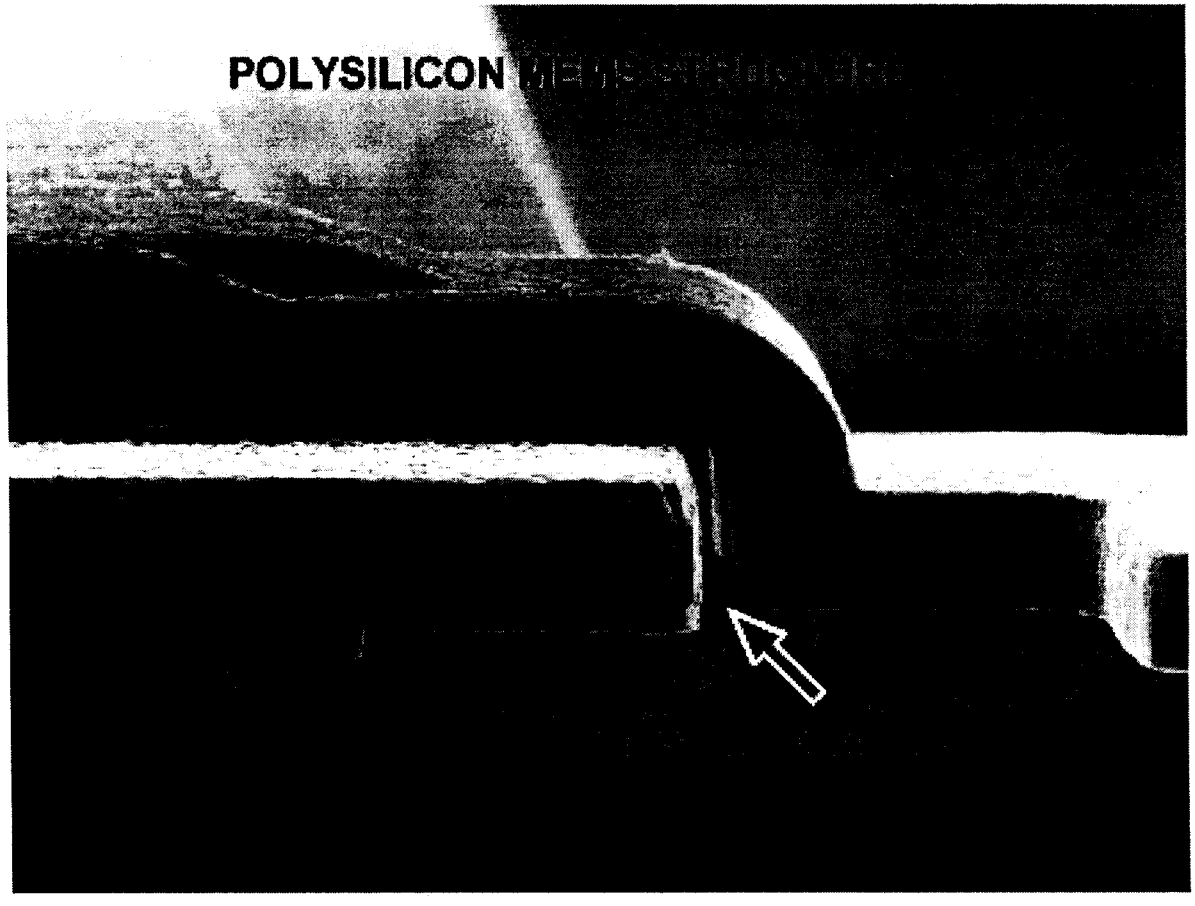
USED FOR PROCESS CHARACTERIZATION AND MATERIAL PROPERTY MEASUREMENTS

REAL-TIME RELIABILITY ANALYSIS



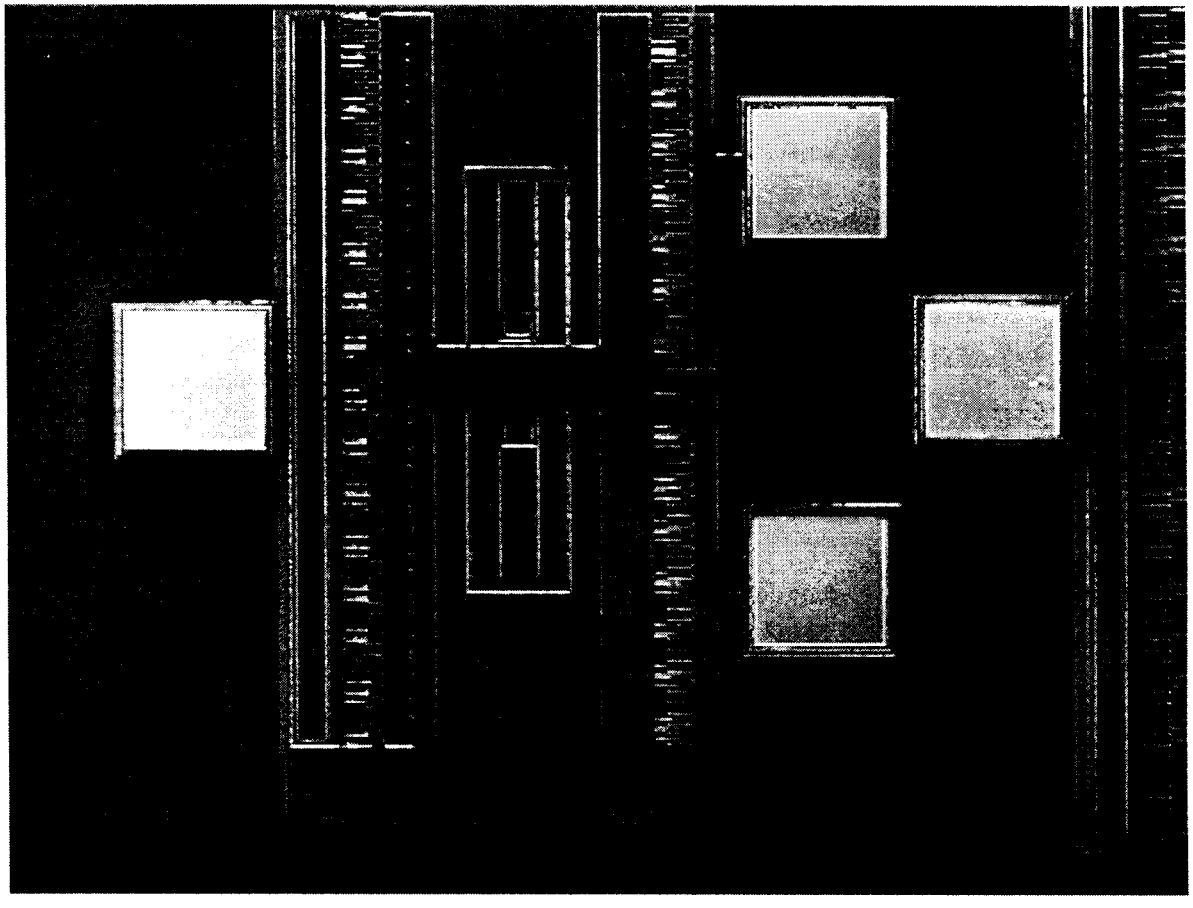
Failure Mode Analysis for Ion Propulsion
In-Situ Investigation Using FIB and SEM

MEMS STRUCTURE POST-RELEASE



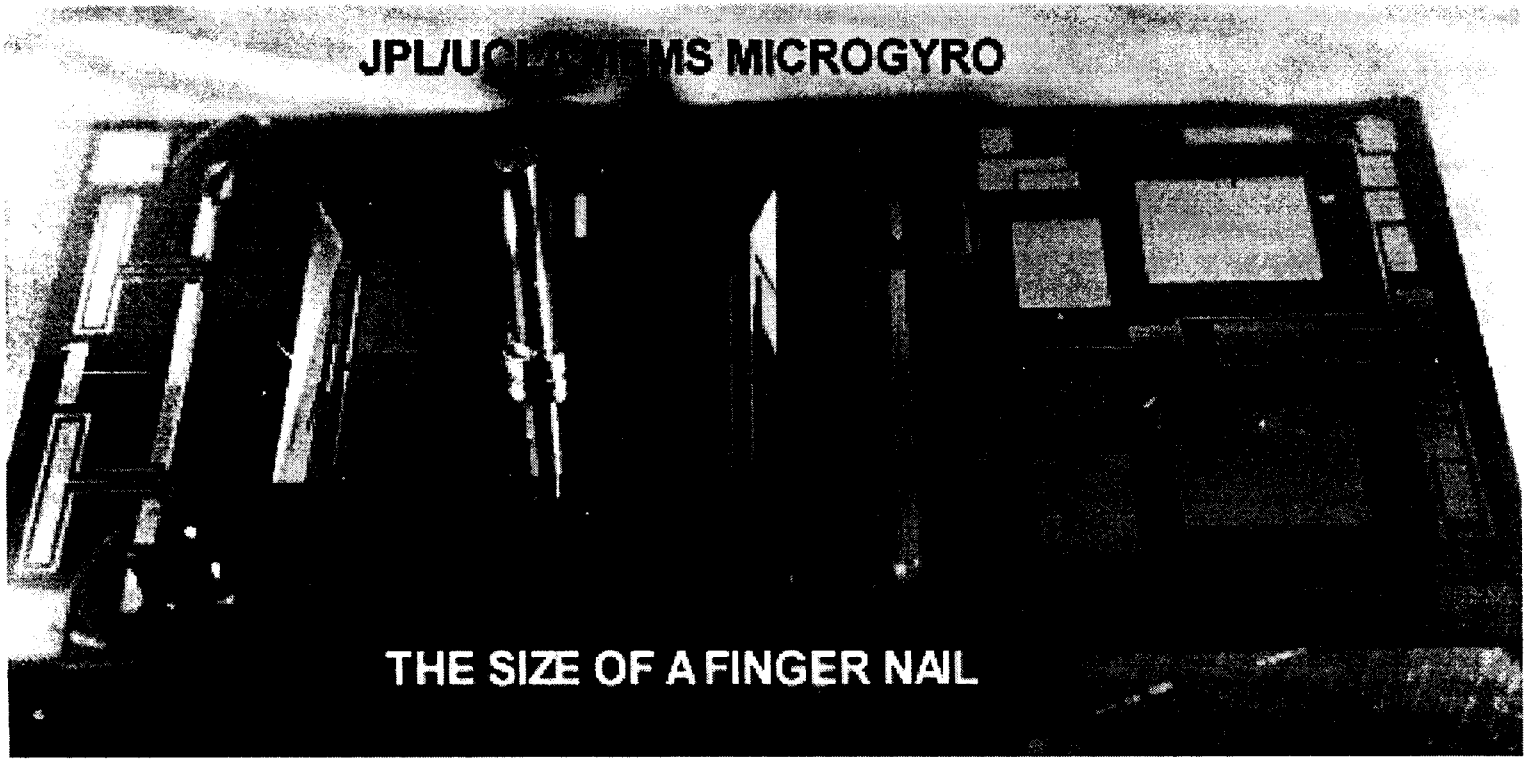
MEMS structure fabricated at Berkeley using polysilicon.

MEMS RESONANT BEAM STRUCTURE



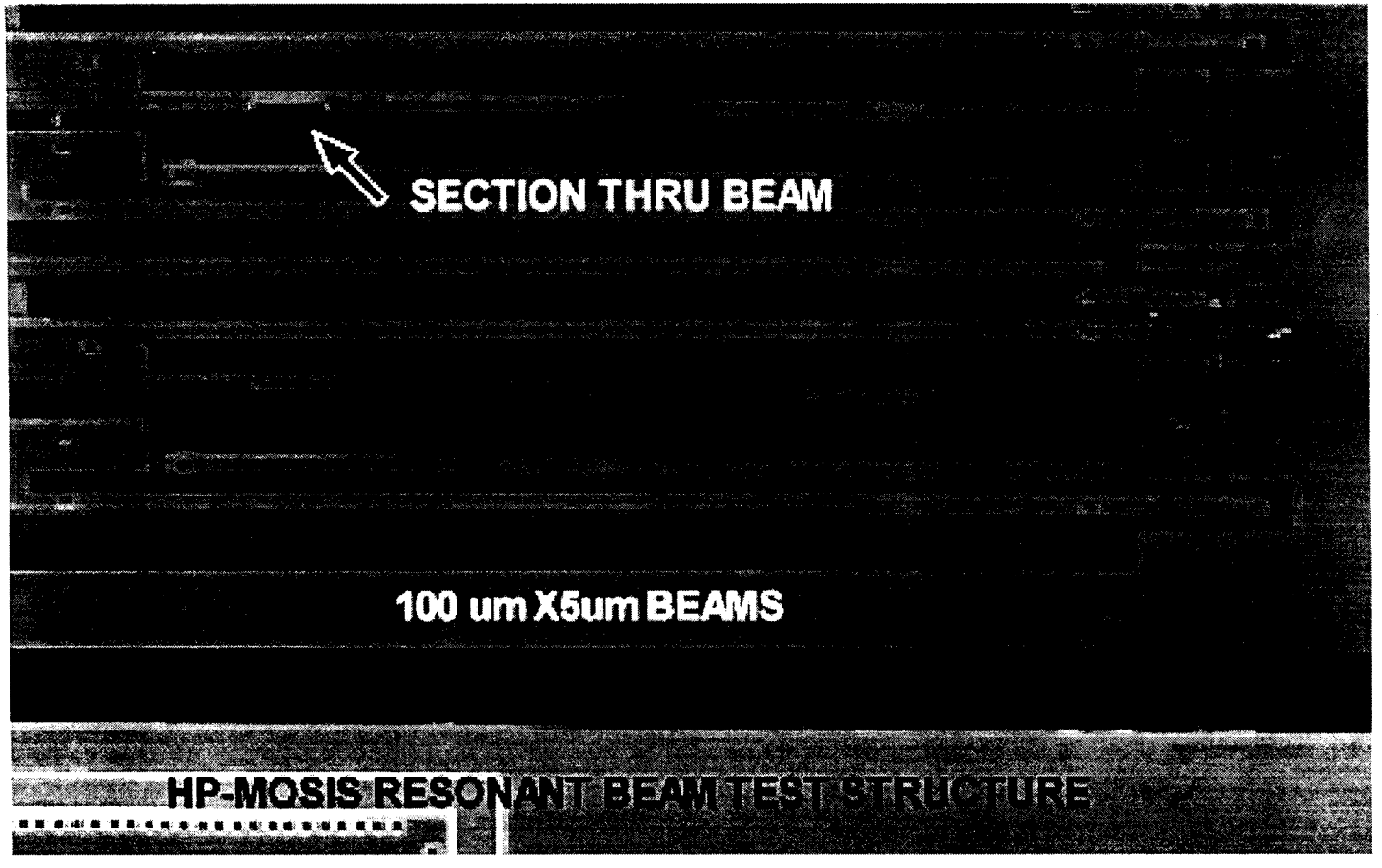
Resonant beam structure used for process characterization and mechanical testing and process evaluation. Fabricated at Berkeley.

JPL/UCLA MICROGYRO



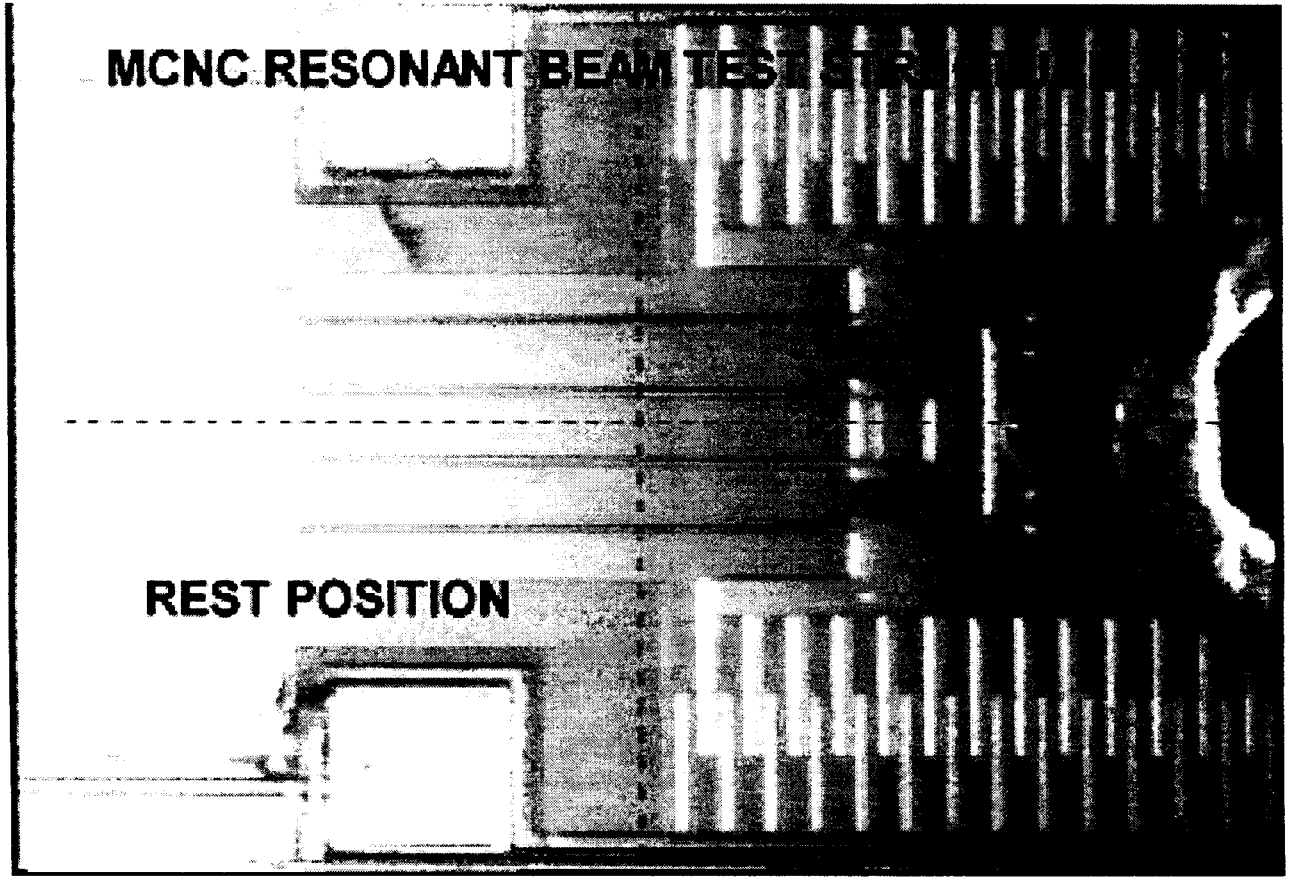
Fabricated at JPL Microdevice Lab for flight on X33.

MEMS RESONANT BEAM TEST STRUCTURE



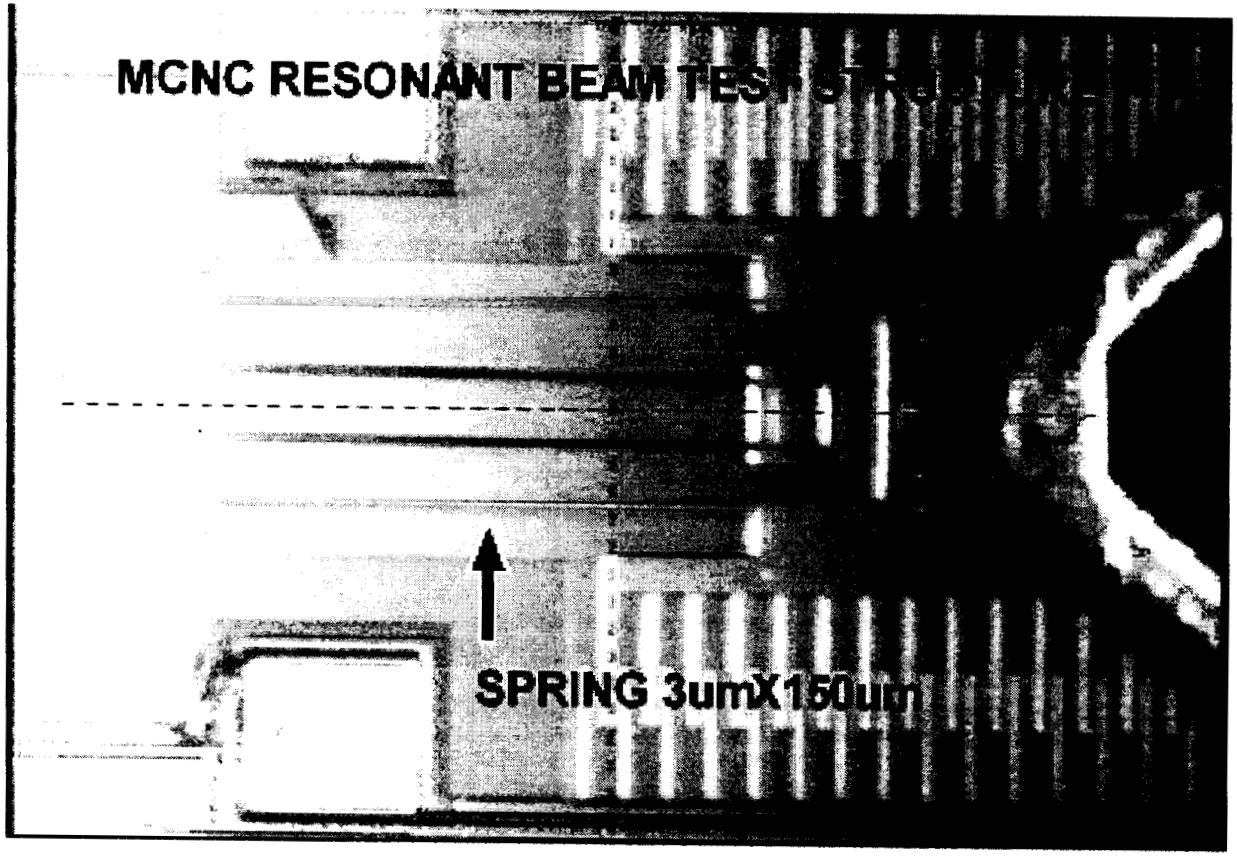
HP-MOSIS CMOS Process for MEMS mechanical and material characterization.

AFM MECHANICAL ACTUATION



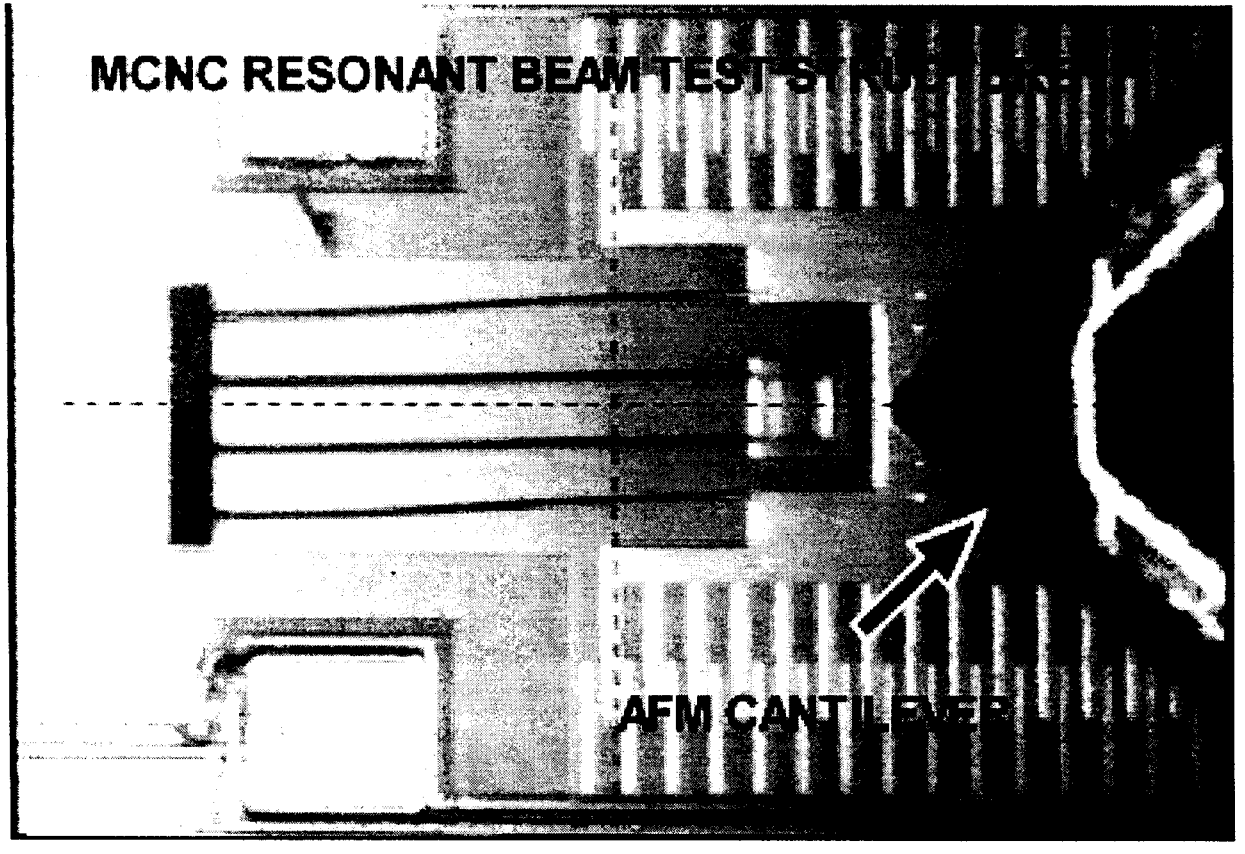
Mechanical measurements to determine spring constant.

AFM MECHANICAL ACTUATION



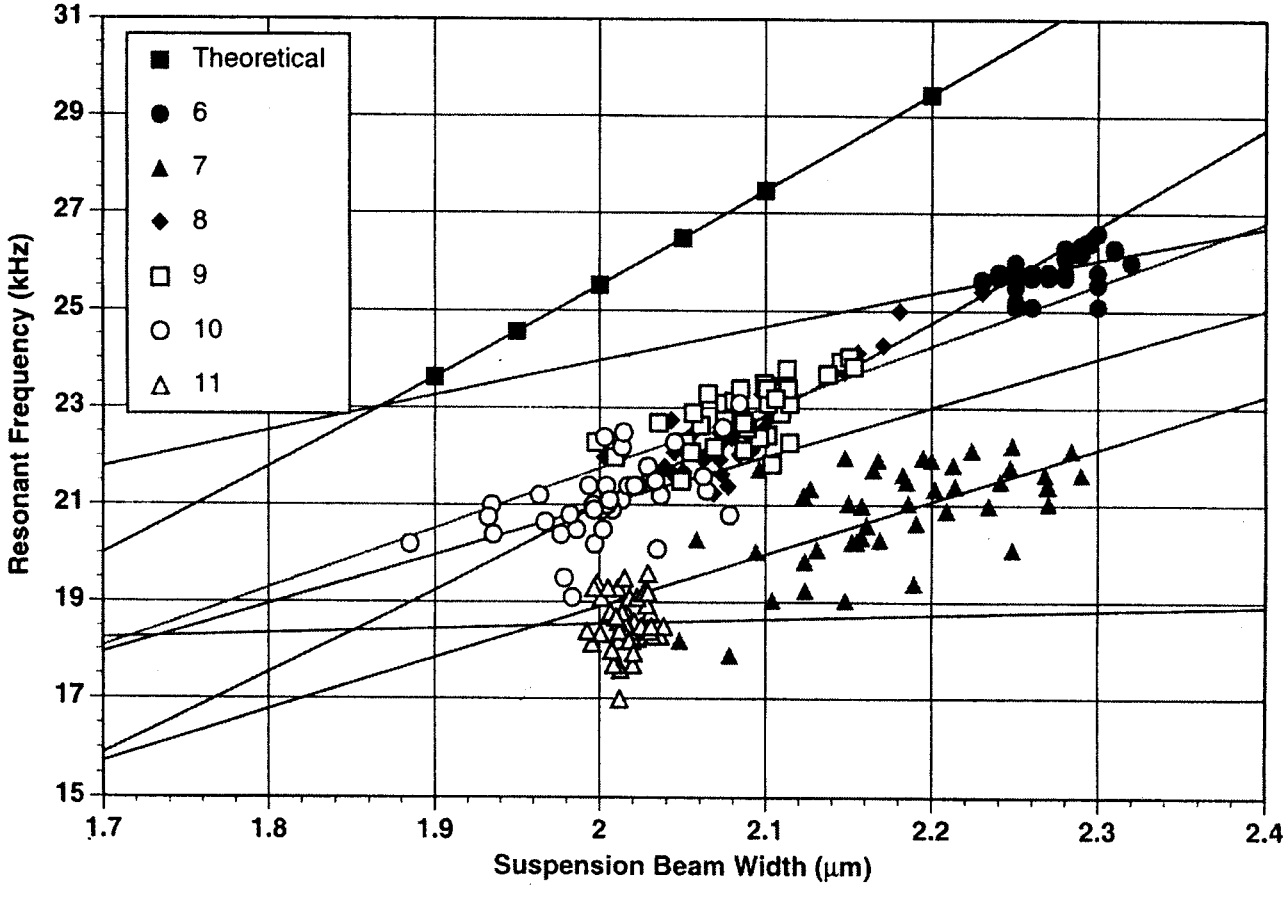
AFM Actuation accomplishes unusual displacement modes.

AFM MECHANICAL ACTUATION



Calibrated Cantilever for force displacement measurements.

MCNC MUMPS PROCESS CHARACTERIZATION



MODELING TECHNIQUES

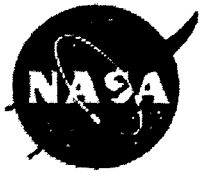
- **LARGE ERRORS EXIST IN MODELING CAPABILITY**
  - ☆ **25.52 kHz Theoretical vs. 16kHz Experimental**
- **NEED COUPLED SOLUTIONS**
  - ☆ **ELECTRO & MECHANICAL**
- **MATERIAL PROPERTIES ARE HIGHLY VARIABLE & HARD TO DETERMINE.**
- **FEEDBACK EXPERIMENTAL RESULTS TO IMPROVE MODELING TECHNIQUES.**
- **DEVELOPE STANDARDIZED TEST PROTOCOLS FOR DESIGN AND VERIFICATION**

YIELD & FAILURE CATEGORIES

MCNC RESONATOR YIELD: 69% (27/45 DEVICES)

- ☆ STICTION - 4
- ☆ POST-PRODUCTION CONTAMINATION - 4
- ☆ HANDLING - 2
- ☆ PACKAGING - 1
- ☆ PRODUCTION - 1
- ☆ UNKNOWN - 2

MEMS CHALLENGES



- **PROCESS CHARACTERIZATION**
- **MECHANICAL SCALING**
- **RISK ASSESMENT**
- **FAILURE ANALYSIS**
- **PROOF OF UTILITY**

Acknowledgements

MEMS RELIABILITY ASSURANCE GROUP JPL

Bob Gauldin, Sid Johnson, Ken Evans, Jim Okuno, Ron Ruiz, Tien Nguyen, Duc Vu

Aerospace Corp.

Nathan Presser, Gary Stupian, Lt. Cary Gunn III

ESA ESTEC

Laurence O'Rourke

Caltech MDL

John Wright

MCNC MUMPS

Dave Koester